Eddy current testing of ferromagnetic materials: modelling of multiple flows in a planar stratified medium

Chiara Zorni, Christophe Reboud, Marc Lambert, Jean-Marc Decitre

EDDY CURRENT TESTING OF FERROMAGNETIC MATERIALS: MODELLING OF MULTIPLE FLAWS IN A PLANAR STRATIFIED MEDIUM

Chiara ZORNI [1,2], Christophe REBOUD [1], Marc LAMBERT [2], Jean-Marc DECITRE [1]

[1] CEA, LIST, Département Imagerie Simulation pour le Contrôle, F-91191 Gif-sur-Yvette, France
[2 Département de Recherche en Electromagnétisme, Laboratoire des Signaux et Systèmes UMR 8506 (CNRS – SUPELEC – Université Paris Sud 11), 3, rue Joliot-Curie, 91192 Gif-sur-Yvette, France

Abstract

Eddy current testing (ECT) is a standard technique in industry for the detection of surface breaking flaws in ferromagnetic materials such as steels. In this context, simulation tools can be used to improve the understanding of experimental signals, optimize the design of sensors or evaluate the performance of ECT procedures. CEA has developed for many years semi-analytical models embedded into the simulation platform CIVA [1] dedicated to non-destructive testing.

Following a previous work [2] carried out at the laboratory in the case of one flaw located in a cylindrical ferromagnetic piece, the development presented herein address the case of multiple interacting flaws located inside a planar, stratified [3] and ferromagnetic medium. Simulation results are obtained through the application of the Volume Integral Method (VIM) [4]. This approach has proved its efficiency when considering canonical geometries, mainly due to the fact that an analytical expressions of dyadic Green operators are available in the spectral domain. While only one integral equation, involving either the electric or the magnetic field, is needed to describe the non-magnetic case completely, in the ferromagnetic case two coupled integral equations have to be solved.

Therefore, when considering the ECT of a single flaw, a system of two differential equations is derived from Maxwell equations. The numerical resolution of the system is carried out using the classical Galerkin variant of the Method of Moments [4]. Finally, the probe response is calculated by application of the Lorentz reciprocity theorem [6]. The resolution has been generalized to the ECT simulation of *N* flaws located in a planar stratified medium. The theoretical approach will be presented, as well as comparisons between simulation results and measured data obtained from the literature, see [7] for example. Combined effects of ferromagnetic layers and interactions between flaws will also be discussed.

References

1. CIVA: State of the art simulation software for Non Destructive Testing, http://www-civa.cea.fr

2. A. Skarlatos, G. Pichenot, D. Lesselier, M. Lambert, and B. Duchêne. "Electromagnetic modeling of a damaged ferromagnetic metal tube via a volume integral formulation," *IEEE Transactions on Magnetics*, **44** (4), pp. 623-632, 2008.

3. S. Paillard, G. Pichenot, M. Lambert, H. Voillaume and N. Dominguez, "A 3D model for eddy current inspection in aeronautics: application to riveted structures", Review of Progress in QNDE, **26**, ed. by D. O. Thomson and D. E. Chimenti, (AIP Conference Proceedings 894, Melville, 2007), pp. 265-272.

4. W.C. Chew. Waves and Fields in Inhomogeneous Media, IEEE Press, Piscataway (2nd edition), 1995.

5. R.F. Harrington. "The Method of Moments," *Electromagnetics. Journal of Electromagnetic Waves and Applications*, **1** (3), pp. 181–200, 1987.

6. B. Auld, F. Muennemann, and M. Riaziat, Nondestructive testing, Chapter 2: Quantitative modelling of flaw responses in eddy current testing, vol. 7, Academic Press, London, 1984

7. H. Huang, T Takagi and T Uchimoto "Fast numerical calculation for crack modeling in eddy current testing of ferromagnetic materials," Journal of Applied Physics, **94** (9), pp. 5866–5872, 2003

‡